Hydrogen Composite Tank Project

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Objectives

- Develop and validate 5,000 psi storage tanks - tank efficiency: 7.5 - 8.5 wt%
- Validate 5,000 psi in-tank pressure regulators - system efficiency: 5.7 wt%
- Develop and validate 10,000 psi storage tanks - tank efficiency: 6 - 6.5 wt%
- Develop and validate 10,000 psi storage systems - system efficiency: 4.5 wt%
- Optimize designs and processes to achieve the DOE cost targets

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Storage section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Cost
- B. Weight and Volume
- D. Durability
- E. Refueling Time
- H. Sufficient Fuel Storage for Acceptable Vehicle Range
- K. Balance-of-Plant (BOP) Components

Approach

- Learn from the successful 100-year history of pressure vessels (industrial, aerospace, CNG)
- Optimize materials, design, and process to improve weight efficiency (5,000 psi tanks)
- Develop & validate volumetrically efficient storage systems (10,000 psi tanks)
- Improve system efficiency (in-tank regulator, balance-of-plant components)
- Validate and certify components (codes & standards, regulatory approvals)
- Work towards cost reduction (technology, economies of scale)

Accomplishments

- Designed industry's first hydrogen 10,000 psi (700 bar) tanks
- Successfully completed validation per European Integrated Hydrogen Project (E.I.H.P.) (Draft 7) and obtained certification (TÜV German Pressure Vessel Code DBV P.18)
- Designed and developed industry's first hydrogen 10,000 psi (700 bar) in-tank pressure regulation system, pressure relief device, manual valve and other balance-of-plant components

- Delivered fully-validated 10,000 psi hydrogen storage systems for automotive original equipment manufacturer (OEM) use
- Demonstrated fast refueling at the rate of 1 kg/minute

Future Directions

- Perform further structural optimization of 10,000 psi tanks in view of improving gravimetric and volumetric efficiencies
- Evaluate lower cost materials to reduce cost
- Evaluate the application of integrated sensors for in-situ structural monitoring
- Evaluate other means of improving volumetric efficiency

Introduction

Possible approaches to hydrogen storage include compression, liquefaction, chemical storage, metal hydrides, and adsorption. Although each storage method has desirable attributes, no approach currently satisfies all the efficiency, size, weight, cost, durability and safety requirements for transportation use. Research continues in these areas, with progress being made in all approaches. Improvements in the energy densities of hydrogen storage systems, reductions in cost, and increased compatibility with available and forecasted systems are required before viable hydrogen energy use will be realized.

The objective of this hydrogen composite tank project was to design, develop, validate, fabricate, and manufacture hydrogen fuel tanks and in-tank regulators along with vehicle integration brackets and isolators and have them delivered to Virginia Tech University and Texas Tech University in support of the Future Truck competition. The 5,000 and 10,000 psi systems developed in this project provide an attractive near-term and possibly medium-term solution for hydrogen storage. The currently validated QUANTUM "TriShield" tank technology meets the usable specific energy, usable energy density, cycle life, refueling rate and limit of loss of hydrogen targets of the DOE for 2005 and approaches the targets for 2010. While cost remains challenging, significant cost reductions are possible with further optimization coupled with economies of scale.

Approach

The QUANTUM advanced composite tank technology incorporates a "TriShield^{TM}" design philosophy. The QUANTUM Type IV TriShield^{TM} cylinder, as illustrated in Figure 1, is comprised of a seamless, one piece, permeation resistant, cross-linked, ultra-high molecular weight polymer liner that is over wrapped with multiple layers of carbon fiber/epoxy laminate and a proprietary external protective layer for impact resistance. TriShield^{TM} hydrogen tanks feature a single-boss opening to minimize leak paths. The path to achieving high gravimetric efficiency is optimization in materials, design and processes.

The TriShield^{TM} hydrogen tank is designed to accommodate QUANTUM's patented in-tank regulator, which confines high gas pressures within

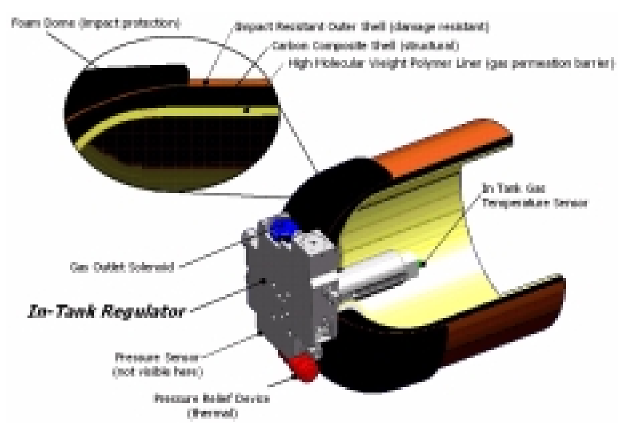

Figure 1. QUANTUM Compressed Hydrogen Storage

the tank and, thus, eliminates high-pressure fuel lines downstream of the fuel storage subsystem. The system cost can be significantly reduced by combining a check valve to assist tank filling, fuel filtering, fuel tank pressure and temperature monitoring, pressure relief device and tank lock-off in the regulation module. Figure 2 shows a complete storage system including storage tanks and balance-of-plant components.

Results

The 5,000 and 10,000-psi tanks developed by QUANTUM Technologies have been validated to meet the requirements of DOT FMVSS304, NGV2-2000 (both modified for hydrogen) and draft E.I.H.P standard. To ensure safety and reliability in an automotive service environment, a number of performance tests have been completed: Burst Tests (2.35 safety margin), Fatigue (45,000 pressure cycles at ambient temperature), Extreme Temperature, Hydrogen Cycling, Bonfire, Severe Drop Impact Test, Flaw Tolerance, Acid Environment, Gunfire Penetration, Accelerated Stress, Permeation and Material Tests. The developed "in-tank regulators" meet the requirements of NGV3.1 and E.I.H.P.

Figure 3 shows the relevance of various components to system-level efficiencies at 5,000 and 10,000 psi storage pressure. It is clear that optimization of the balance-of-plant components is critical to achieve system-level gravimetric efficiency, especially when multiple tanks are utilized. Storage at 10,000 psi provides important

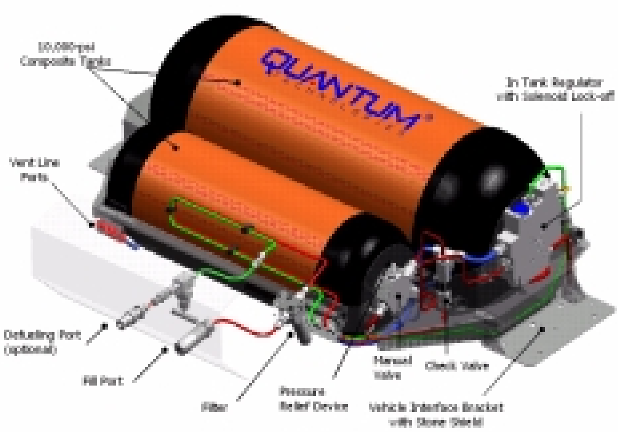

Figure 2. Compressed Hydrogen Storage System

volumetric advantages without significant energy penalty (see Figure 4).

Table 1 shows the DOE FreedomCAR targets for 2005 and 2010, in relation to the current status of 10,000 psi storage. It can be seen that the biggest challenge is cost, which needs to be reduced by a factor of 20. It is anticipated that cost reduction will include optimization through technology (50 to 75% reduction), followed by economies of scale (factor of 10).

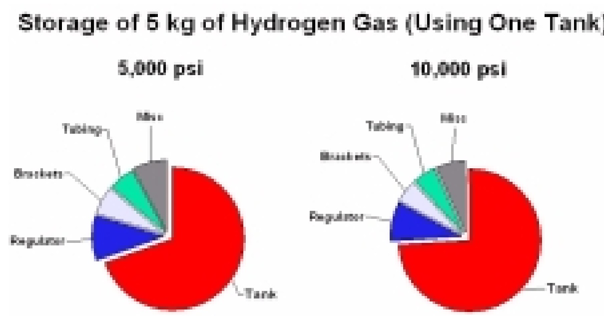

Figure 3. System-Level Weight Efficiency

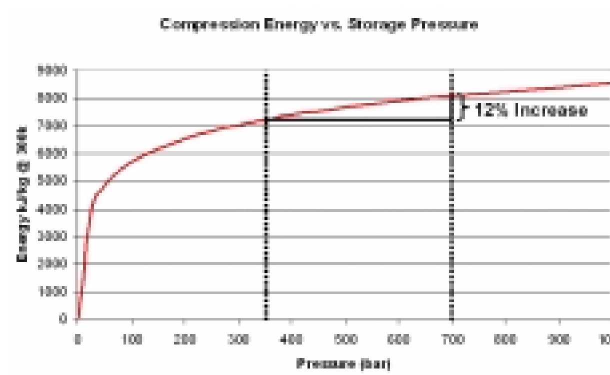

Figure 4. Volumetric Efficiency: 5,000 psi vs 10,000 psi Storage

Table 1. DOE FreedomCAR Targets vs. Status

Parameter	2005	2010	Status
Usable Specific Energy (kWh/kg)	1.5	2	1.9
Usable Energy Density (kWh/L)	1.2	1.5	1.3
Cost ($/kWh)	6	4	114
Cycle Life (1/4 to full Cycles)	500	1,000	15,000 - 45,000
Refueling Rate (kg H_2/min)	0.5	1.5	1
Loss of Usable Hydrogen (grams)	1	0.1	0.0005

Conclusions

- The 5,000 psi and 10,000 psi compressed hydrogen storage systems developed and validated in this project provide a convenient near-term solution, and are currently available and successfully deployed on fuel cell vehicles.
- DOE 2005 performance targets are achievable.
- Storage is a significant cost factor in overall fuel cell system cost.
- Carbon fiber and stainless steel hardware costs represent over 90% of the costs.
- Design and process improvements to address storage tank costs are on-going.

FY 2003 Publications/Presentations

1. Andris R. Abele, "Advanced Hydrogen Storage Systems", Hydrogen and Fuel Cells 2003 Conference and Trade Show, Vancouver (June 2003).
2. Brian Jenkins, "Advanced Hydrogen Fuel Systems for Fuel Cell Vehicles", 1st International Conference on Fuel Cell Science & Energy Technology (April 2003).